4.0 DISCUSSION

The primary criteria specified by the ACOE for this study were met for both spillbay test conditions. These were: recapture rates of tagged fish to exceed 80%, recapture times ≤1 h, handling mortality ≤10%, precision of the survival estimate to be within ±5% at the 90% probability level, the characterization of injuries, and fish condition. The realized recapture rates of treatment fish (both alive and dead physically retrieved) were ≥97% in both test conditions; the average recapture times of treatment and control groups were <8 min; the assumed and observed control mortality was <4%; and the precision (ε) on both the immediate (1 h) and 48 h estimated survival rates was <±5%, 90% of the time. Only one targeted species (chinook salmon) was involved in this study, no non-targeted species were handled. The study succeeded in identifying the location and type of fish injury. Finally, the study identified a potential fish passage problem area within the Powerhouse 2 ice and trash sluice and an area of potential predation on juvenile emigrants at the outfall of Powerhouse 1 sluice.

All recaptured fish were examined immediately upon recapture and at 48 h (fish were reanesthetized to reduce stress) for external injuries. Those which died were also necropsied to examine for internal injuries. This examination procedure proved to be ideal for assessing passage related injuries for alive fish while still maintaining the fish in a vigorous condition.

The following explicit assumptions were made with respect to use of the tag-recapture technique. Handling, tagging, and release do not differentially affect survival rates of treatment and control groups; recapture probabilities for the treatment and control groups are the same; and recapture boat crews do not differentially select retrieval of either group of fish. These assumptions were considered satisfied as follows. The differential effects of handling, tagging, and release were not evident on recaptured fish held for 48 h observation periods in either test scenario. Little mortality of recaptured fish occurred in either the treatment or control group (99% survival). The potential bias due to non-selective retrieval of treatment and control groups was minimized by not assigning a specific boat crew to retrieve either treatment or control group fish. Any of the crew that was available for fish recapture was assigned the task of individual fish retrieval. The recapture boat crews were trained in fish handling and retrieved the buoyed fish with minimal damage. The average recapture times for the treatment and control groups were similar.

The assumption that the treatment and control group fish were equally vulnerable to recapture appeared violated, although not statistically significant, to some extent for the flow deflector test condition (spillbay 4), but not for the non-flow deflector test scenario (spillbay 2). A slightly higher proportion of the flow deflector treatment group (0.993) fish was recaptured than the control group

(0.969). The lower recapture probability (0.961) of controls was due to tag dislodgement or non-recaptures in 11 of 280 fish; only 2 of 280 treatment (0.007) fish were either not recaptured or dislodged tags. However, recapture probability for spillbay 2 (0.969) was similar to the controls (0.961). In the spillbay 2 treatment group, 8 fish lost tags and 1 was not recaptured. The almost identical recapture probability of the spillbay 2 treatment and control groups and somewhat different recapture probabilities between spillbay 4 treatment and control groups indicated that not all fish were homogeneously distributed after exiting the induction hose. The non-availability of discharge from an adjacent spillbay when the control and spillbay 2 treatment fish were released tended to move the fish towards the shoreline. Some of these fish became entrapped in crevices of the shoreline rip rap and eddies and were difficult to retrieve. In contrast, spillbay 4 treatment fish remained offshore in the tailrace, largely due to discharge from spillbay 2, and thus were easier to retrieve. Discharge from spillbay 1 may have prevented the spillbay 2 treatment and control group fish from surfacing near the shore but could have interfered with the attraction flow for upstream adult migrants.

One of the considerations for the study was to minimize the number of fish used for each experiment without sacrificing precision (ε). Mathur *et al*. (1996a) proposed that a sample size of 250 fish (treatment and control each) may be adequate for achieving a precision (ε)of $\leq\pm5\%$, 90% of the time, if the recapture and control survival probabilities exceed 0.95. This combination was achieved in the present study, the sample size used was 280 fish for the two treatments with a common shared control of 280 fish. The release of a common control group of fish for two simultaneous treatment releases on the same day further reduced the need for additional fish without sacrificing precision. This finding is similar to that reported for the turbine passage survival research on chinook salmon at Lower Granite Dam (Normandeau Associates *et al*. 1995). Consistency in these results suggests that if the fish supply is limited, it is possible to achieve the anticipated precision using fewer controls if evaluation of more than one treatment effect is desired.

Spillbays inflicted few (1.3% when adjusted for controls) and relatively minor injuries. These low observed injury rates may be attributed to condition of test fish, high spill rate tested, relatively unobstructed fish passage routes, and physical design of the spillbays. The study used hatchery-reared unsmolted fish. Although smolted fish are prone to greater descaling than unsmolted fish the scale loss patterns indicative of scraping structural components were rare. Thus, the magnitude of potential descaling at the spill conditions tested may be independent of the physiological state of the fish. However, it is unknown whether extremely turbulent spill would cause substantial patchy descaling on smolted fish.

The type and magnitude of injury exhibited by juvenile salmon at Bonneville were slightly different than those observed at The Dalles Dam (Normandeau Associates *et al.* 1996). At The Dalles Dam fish were passed through three spillbays; one was unmodified, the other two had bulkheads placed upstream of the tainter gate that direct flow and fish through an I configuration or an overflow weir. Additionally, energy dissipators, designated as baffles or "dragon's teeth", intercept some of the spillage downstream of each spillbay along with a 13 ft high concrete vertical end sill downstream of the baffles. Injury rates observed at the three spillbays ranged from 0.4 to 2.3%. Eye or gill injuries were most prevalent for the three test conditions. The dentated flow dissipators likely contributed to some of the injuries.

The single spill rate of 12,000 cfs tested at Bonneville spillbays was typical of that commonly encountered by salmonid emigrants and is probably adequate in maintaining sufficient depth, particularly over the flow deflector area, and the dentates downstream, to minimize the incidence of injury and mortality. Because only a single spill rate was tested it is not possible to predict the spill rate that would provide optimal fish condition. However, a spillway flow deflector effect study at Lower Monumental Dam on the Snake River did not reveal differences in survival of chinook fingerlings at two spill rates tested (2,800 cfs and 13,100 cfs); the estimated survival, as determined from downstream recovery ratios of treatment and control fish at McNary Dam, was 84% at 2,800 cfs and 83% at 13,100 cfs (Long *et al.* 1972).

Despite differences in spillway configuration, presence or absence of flow deflectors and baffles, hydraulics, and species the estimates of survival probabilities of the present study are within the range of statistical variation reported in other studies at spillways with less than 100 ft height (Schoeneman *et al.* 1961; Ledgerwood *et al.* 1990; Heisey *et al.* 1993). Schoeneman *et al.* (1961) reported spillway passage survival probability of 0.98±0.02 (95% confidence intervals) for chinook salmon at McNary Dam (about 146 miles upstream of Bonneville Dam, net head 90 ft) and Big Cliff Dam (head 90 ft) on the Santiam River; their estimate was based on pooled data from the two sites due to statistical similarity. Heinle and Olson (1981) reported a survival probability of 0.996 for coho salmon (*Oncorhynchus kisutch*) in passage over the spillway at Rocky Reach Dam on the Columbia River (about 228 mi upstream of Bonneville Dam, 90 ft head). Ledgerwood *et al.* (1990), in a long-term comparative survival study of juvenile chinook salmon in passage through various exit routes at Bonneville Dam, estimated spillway passage at 1.0. It is interesting to note that the above studies utilized tag-recapture methodologies (e.g., freeze branding, coded wire tags, etc.) that had low recapture rates (<5%) and were not designed to separate direct and indirect effects of passage. Heisey *et al.*

(1993) reported survival rate of 96% for Atlantic salmon smolts (*Salmo salar*) in passage through sluices at two hydro dams on the Connecticut River.

Adverse effects of flow deflectors on fish survival were not evident in the present study. This finding seems to be consistent with that reported by others, though the tag-recapture methodology differed (Johnsen and Dawley 1974; Long *et al.* 1975). Johnsen and Dawley (1974) reported no decrease in the survival of juvenile salmon in passage over spillway deflectors at the Bonneville Dam; recapture of fish (freeze branded) occurred several miles downstream of the dam and over many days. Long *et al.* (1975) reported higher steelhead smolts (Oncorhynchus mykiss) survival in passage over flow deflectors at Lower Monumental Dam on the Snake River; the smolt survival was 97.8% in passage through spillbays equipped with flow deflectors and 74.5% through standard spillbays. The study on chinook salmon smolts at Lower Monumental Dam reported survival of 83.1% to 84% in passage through a spillbay with flow deflectors. These estimates were based on fish recoveries downstream at McNary Dam.

The principal causal mechanism for injury/mortality to fishes transported via spillways have been attributed to shear forces, turbulence, rapid deceleration, terminal velocity, impact against the base of the spillbay, scraping against the rough concrete face of the spillbay, and rapid pressure change (Ruggles and Murray 1983). However, experiments have not been conducted to identify the relative importance of these factors in affecting fish condition/mortality reported injuries sustained included eye damage, embolism, hemorrhaging, and abrasions (Ruggles and Murray 1983). Although the number of injured fish was relatively small in both experiments at Bonneville, the study succeeded to a certain extent in identifying the probable sources of injury/mortality. The scrape and bruise wounds could have been caused by the fish physically contacting structural components of the spillbay including the tainter gate, flow deflector, and/or dentates. Hemorrhaging and bulging eyes were most likely strike-related as well. Although bulging eyes have been attributed to pressure effects the absence of other corroborating symptoms on necropsied fish (e.g., expanded or burst air bladders, entrapped gas bubbles, etc.) suggests that pressure change was not a probable cause (Cramer and Oligher 1964). Which of the various structural components contribute most to injuries was not apparent from the present study; however, because survival and condition of fish was similar for the two test conditions, flow deflectors do not appear to exasperate conditions.

5.0 CONCLUSIONS

The survival and condition of hatchery-reared juvenile chinook salmon (100 to 170 mm, average 124 mm total length) in passage over spillbay 2 (without flow deflector) and spillbay 4 (equipped with a flow deflector) at Bonneville Dam were estimated using the HI-Z tag-recapture technique (balloon tags). These parameters were reliably estimated for only the direct effects of spillway passage at two spillbays each discharging about 12,000 cfs. Only one spillage rate was tested.

The primary criteria set forth by the ACOE, objectives, and assumptions of the research were met. A combination of high recapture probabilities (treatment fish >0.97 and control >0.96) and high control survival (>0.96) reduced the sample size requirements without sacrificing precision. With the observed recapture and control survival probabilities a paired release of 280 treatment and control fish each was sufficient to achieve a precision (ε) level of <±4%, 90% of the time. Additionally, the release of a single control group for two treatment groups reduced the number of fish needed for a comparable matched-paired release experiment.

The estimated 48 h fish survival probabilities of 1.0 in both experiments suggested that the spillbay configuration (with or without flow deflectors) at the hydraulic conditions tested had no effect on survival of juvenile chinook salmon. These survival probabilities are slightly higher than reported (0.98) in many other spill investigations.

Even though the estimated survival probabilities were the maximum possible, a small proportion of fish suffered injuries (1.3%), were descaled (0.5%) or lost equilibrium (0.5%). The most probable cause of injury and scale loss was attributed to contacts with hard surfaces of the spillbay and tainter gate. Primary injuries observed were hemorrhaging, bruises, and bulging eyes. Although the small sample size of injured fish precludes determining whether injury types are significantly different for the two test conditions, 4 of 271 fish recaptured from the non-flow deflector spillbay experiment had eye injuries while only 1 of 278 fish passed over the flow deflector showed an eye injury. Pressure or shear-related injuries were not readily apparent.

Additional smaller releases (100 fish each) of fish passed through ice and trash sluices at Powerhouses 1 and 2 provided the general condition of fish and identified some potential passage problems to emigrants. Injury rate was low (1.1%) at both sluices. A potential exists at Powerhouse 2 sluice for some fish to be diverted into a screened side channel and become "trapped". Fish using Powerhouse 1 sluice may be vulnerable to potential predation at the outfall area. However, this may need verification with detailed monitoring of the area.

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